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Excitons in nitride-based low dimensional systems

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The exciton binding energy is large (25–27 meV) in bulk GaN. The coupling with the electromagnetic is large too. Together with my friend Alexey Kavokin, I predicted a Rabbi oscillation splitting of some 45 meV in GaN based microcavities.

Cubic GaN-AlGaN quantum wells can theoretically lead to an improvement of the optical response compared to the case of bulk c-GaN due to the know well known physics of the 2D confinement in type I quantum wells. This is not systematic for quantum wells based on wurtzite GaN and AlGaN due to difference of the spontaneous polarization of the two materials which together with piezoelectric field effect produce an efficient Quantum Confined Stark Effect. Consequently the optical transition can be boosted either toward shorter wavelength than the one of bulk GaN or can be boosted in the realm of long wavelength radiations, depending on well width, at the first order.

I first show using cw spectroscopy arguments, and samples grown by molecular beam epitaxy, that the magnitude of the internal electric field depends on the aluminum composition, and of the ratio between the width of the well layers relatively to the width of the barriers. In particular for aluminum compositions ranging up to 27 percents, it is measured that for well width larger than 12 monolayers (3 nm) the photoluminescence energy is lower than the bandgap of bulk GaN. Comparing cw photoluminescence and reflectance spectra reveals a stokes-shift of the photoluminescence compared to the reflectance at low temperature as an evidence of a localized nature of the excitons that are observed in photoluminescence, at low temperatures. Increasing the temperature gives an excess of kinetic energy, that can facilitate the exciton detrapping. The relative ratio of free to bound excitons promotes the free exciton population so that, at high temperature, photoluminescence is dominated by free exciton recombination. The internal electric field localizes electrons and holes at different interfaces. Envelope function calculations indicate that, when the well-width increases, this drastically reduces the overlap between their wavefunctions and increases the radiative decay time, but has poorer influence at the scale of the exciton binding energy (long range interaction). Simple envelope function calculation also indicates that the in-plane extension of the hole and electron wavefunctions is comparable in size with the average aluminum-aluminum separation for alloy compositions ranging up to at least 30 percents. The interfacial exciton localization results of the comparable values of the Bohr radii and of the characteristics length of the alloy disorder.

Time resolved spectroscopy measurements are performed which permitt to extract both the radiative and non-radiative contributions to the photoluminescence decays. These experiments were achieved on single quantum wells, assymetric multiple quantum wells and superlattices. It could then be possible to discriminate between the different contributions that rule the non-radiative recombinations mechanisms. The strength of the coupling with the LO phon is reported to increase when increasing the well width. This we compare to what is observed for GaInN-GaN quantum wells. For that semiconductors combination, the structural disorder occurs in the confining material: GaInN, and the localization

phenomena are more crucial than for GaN-AlGaN. By comparing photoluminescence and photoreflectance spectra taken on a series of InGaN-GaN quantum wells grown under identical conditions except the growth time of the InGaN layers, the Quantum Confined Stark Effect (QCSE) could be monitored without changing the nanotexture of the alloy layers. The results indicates that, for quantum wells which radiate in the red, the contribution of the QCSE superimposes to an intrinsic localization phenomena of the carriers in the InGaN alloy, and is larger by one order of magnitude. I show that the interpretation of data for samples that emit from the blue to the red can provide only partial conclusions if both localization effects and (QCSE) are not taken into consideration. This is further comfirmed by similar experiments performed on Stranski–Krastanov GaInN-GaN quantum boxes. The net result is that the localization of the exciton is occurs in alloy regions very small, smaller than 1 nanometer, in fairly nice agreement with the ideas that are defended by Kevin O'Donnell. Although heuristic effective mass calculations are helpfull for interpreting optical properties of GaN-AlGaN quantum wells one has to be more cautious if using them for GaInN-GaN quantum wells. Indeed, slightly changing the growth temperature but not the well width alters the colour of the light emitted by the samples which indicates that the nanotexture of the alloy is changed.

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